Modeling SAR Backscattering of Bright Flows and Dark Spots on Titan

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MODELING SAR BACKSCATTERING OF BRIGHT FLOWS AND DARK SPOTS ON TITAN. Ph. Paillou[1], M. Crapeau[1], Ch. Elachi[2], S. Wall[2] and P. Encrenaz[3], [1]Observatoire de Bordeaux, UMR 5804, 2 rue de l'Observatoire, 33270 Floirac, France (paillou@obs.u-bordeaux1.fr), [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, [3]Observatoire de Paris, LERMA, 75014 Paris, France.

Introduction: The SAR imaging mode of the Cassini Radar instrument allows to map the surface of Titan with a high-resolution [1]. The first Cassini close flyby Ta was acquired on 26 October 2004 and revealed a complex surface, with areas of low relief and dome-like volcanic constructs, flows and sinuous channels [1]. In particular, channels and fan-like features with a strong radar backscattering were observed; the strong SAR signal was explained by a high component of volume scattering [2]. Such fan-like features, extending from tens of kilometers to more than 200 km in length, could be the result of cryovolcanism [3]. Also, a number of radar-dark spots up to 30 km across were observed: they could correspond to smooth hydrocarbon deposits [4]. We present here a first analysis of radar-bright and radar-dark features of the Ta flyby, based on the use of classical SAR backscattering models. We considered two main materials which could constitute the surface of Titan, tholins and water-ammonia ice, and modeled both the single and two-layer cases, taking into account volume and sub-surface scattering. First results show that SAR-bright regions can be explained by both strong volume scattering in a water ice + ammonia layer or by the effect of a thin layer of such material covering a tholin substratum. Radar-dark spots can also be modeled with two scenarios: a rough tholin surface or a smooth one with some volume scattering.

Radar-bright Regions: We studied the SAR image extract presented in Figure 1. We considered two regions, region #1 being characterized by a lower SAR backscattering typical of a "surrounding SAR-dark material", while region #2 corresponds to SAR-bright fan-like features which could be related to flow features covering the SAR-dark material. SAR illumination is from the left, and the terrain is supposed to be rather flat. The studied region is located around coordinates 50.92°N, 79.35°W, and the SAR incidence angle there is close to 30^o. We shall consider in the following that the SAR-dark material could be representative of a tholin-composed surface, of dielectric constant estimated to $\varepsilon = 2.2\text{-}0.01i$ [5], within the *2-3* range obtained from the radiometry mode [1]. If of cryovolcanic origin, SAR-bright flows could be composed of a mixture of water ice and ammonia, whose dielectric constant is estimated to $\varepsilon = 4.5\text{-}0.04i$ [6]. We worked on SAR normalized cross-section values (σ^0), not corrected for incidence-angle effect, at a resolution of *175 m* per pixel: region #1 presents an average backscattered power of *-7.5 dB*, while region #2 corresponds to a σ^0 value around *0 dB*.

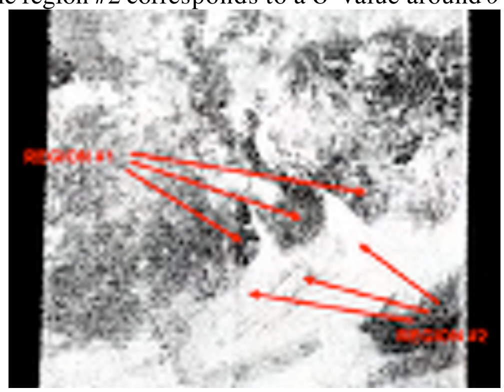

Figure 1. The radar-bright study site in Ta SAR data.

At Ku-band ($\lambda_0 = 2.18\ cm$), a SAR should penetrate around *0.5 m* in the Titan's surface. We then considered a two-layer model for the first meter of the Titan's sub-surface: a superficial layer of material #1, of thickness d, covers a sub-surface layer of material #2. The first layer is characterized by its dielectric constant (ε_1', ε_1''), its surface roughness (σ_1, L_1) and its albedo a_1. The second layer is also characterized by its roughness (σ_2, L_2,), dielectric constant (ε_2', ε_2'') and its albedo a_2. In order to take into account various surface roughness conditions, we had to deal with different backscattering models: IEM (Integral Equation Model) [7] for smooth to medium-rough surfaces, PO (Physical Optics) model [8] and GO (Geometric Optics) model [9] for rough surfaces. We also had to take into account a volume scattering term in order to simulate the diffusion effects of heterogeneities in the materials [10], and we also considered a sub-surface component, which is the surface scattering term of the second layer attenuated by its propagation through the first layer.

First, we computed the surface scattering component for both tholins and water ice / ammonia mixture at an incidence angle $\theta = 30^o$ with surface roughness parameters varying: $0 < \sigma < 2\ cm$ and $0 < L < 4\ cm$. For tholins, a maximum backscattered power of *-8.28 dB* is reached for parameter values $\sigma = 0.65\ cm$ and $L = 2.25\ cm$. Clearly, some volume scattering contribution is still needed to reach the value *-7.5 dB* for region #1, if composed of tholin-like materials. For a low albedo value $a=0.02$, the volume scattering term is *-16.56 dB*, which added to the surface term yields a total backscattered power of *-7.68 dB*: a very high volume scattering effect is not required to explain for the SAR response of region #1. The maximum backscattered power for a water ice / ammonia mixture is obtained for $\sigma = 1.10\ cm$ and $L = 3.80\ cm$ and is not higher than $-2.95\ dB$, i.e. far from the observed $0\ dB$ of region #2. Such a strong σ^0 value cannot be reached considering only surface scattering. We have to add a significant volume scattering term, corresponding to a high albedo value: taking $a = 0.5$ produces a total backscattered power of $0.26\ dB$ for region #2. In this latter case, the volume scattering term is $-2.55\ dB$, i.e. more important than the surface scattering term. Another possibility to model SAR-bright flows is to consider a two-layer model, where a thin water ice + ammonia layer covers a tholin layer. Surface scattering can be enhanced by the presence of a thin covering layer which lowers the radar incidence angle on the surface [11]: a Ku-band radar wave arriving with an incidence angle of $\theta = 30^o$ on a material of dielectric constant $\varepsilon = 4.5\text{-}0.04i$ is transmitted to the sub-surface with an angle $\theta_t = 13.6^o$. For such an incidence angle, a maximum surface scattering of $-2.73\ dB$ can be obtained for a covered tholin layer of roughness parameters $\sigma = 0.40\ cm$ and $L = 3.30\ cm$. In order to get the total backscattered power for the two-layer configuration, we have to compute the sum of the surface σ^0_{1Spp} and volume σ^0_{1Vpp} contribution of the first layer, and the sub-surface σ^0_{2SSpp} and volume σ^0_{2Vpp} contribution of the second layer. For a two-layer model made of a thin water ice + ammonia layer of thickness $d = 5\ cm$ and roughness parameters $\sigma_1 = 1.10\ cm$ and $L_1 = 3.80\ cm$, of very low albedo value $a_1 = 0.01$, covering a tholin layer of roughness parameters $\sigma_2 = 0.40\ cm$ and $L_2 = 3.30\ cm$ with a low albedo value $a_2 = 0.15$, we computed a total backscattered power $\sigma^0 = -0.83\ dB$, corresponding to $\sigma^0_{1Spp} = -2.95\ dB$, $\sigma^0_{1Vpp} = -29.57\ dB$, $\sigma^0_{2SSpp} = -6.32\ dB$ and $\sigma^0_{2Vpp} = -10.76\ dB$. The σ^0 value obtained is closed to the observed one for SAR-bright flows, which could then be described as a thin layer of water ice + ammonia covering tholins.

Radar-dark Spots: Figure 2 shows two radar-dark spots observed in the Ta flyby SAR data. These regions are much darker than the rest of the SAR image strip, with backscattered power ranging between $-13\ dB$ and $-10\ dB$. Both are roughly circular of diameter around 17 km. Radar-dark spot A is located at 51.23°N, 76.53°W and corresponds to a SAR incidence angle close to 30^o, while radar-dark spot is located at 49.48°N, 69.73°W and corresponds to a SAR incidence angle close to 23^o. Passive radiometry data show that dark spots are $3\ K$ higher in brightness temperature than their surroundings, which is consistent with a dielectric constant around 2. They were interpreted as possible smooth hydrocarbon deposits [4].

Figure 2. Radar-dark spot A and B in Ta SAR data .

The low backscattered power of SAR-dark spots can be easily reproduced using a simple one-layer surface scattering model, without any volume scattering component. We considered surface scattering for both tholin and water ice + ammonia materials, with surface roughness parameters varying: $0 < \sigma < 2\ cm$ and $0 < L < 4\ cm$. For both incidence angles $\theta = 30^o$ and $\theta = 23^o$, we only kept the computed backscattered power between $-13\ dB$ and $-10\ dB$, corresponding to the observed σ^0 for radar-dark spots. Results show that few (σ, L) combinations of roughness parameters for the water ice + ammonia case can produce σ^0 values in the observed range, while a large region of the roughness parameter plane fall into this range for tholins. For both incidence angles, a rough tholin surface of parameters $1 < \sigma < 2\ cm$ and $2 < L < 4\ cm$ produces a backscattered power in the observed range. So a rough tholin-covered surface could be responsible for radar-dark spots, although smoother surfaces with some volume scattering contribution can also produce the same result. For instance, at an incidence angle $\theta = 30^o$, a smooth tholin surface of roughness parameters $\sigma = 0.10\ cm$ and $L = 1.00\ cm$ with an albedo $a = 0.05$ produces a total backscattered power $\sigma^0 = -11.47\ dB$: the surface scattering component is $-18.08\ dB$ (IEM domain), and the volume scattering component is $-12.54\ dB$.

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